Applicant: Michael A. Pouchak et al.
Serial No.: New US Patent Application
Filed: March 25, 2004
For: MULTI-STAGE BOILER STAGING AND MODULATION CONTROL METHODS AND CONTROLLERS
Docket: H0005606-9952(1161.1126101)
Sheet 1 of 18

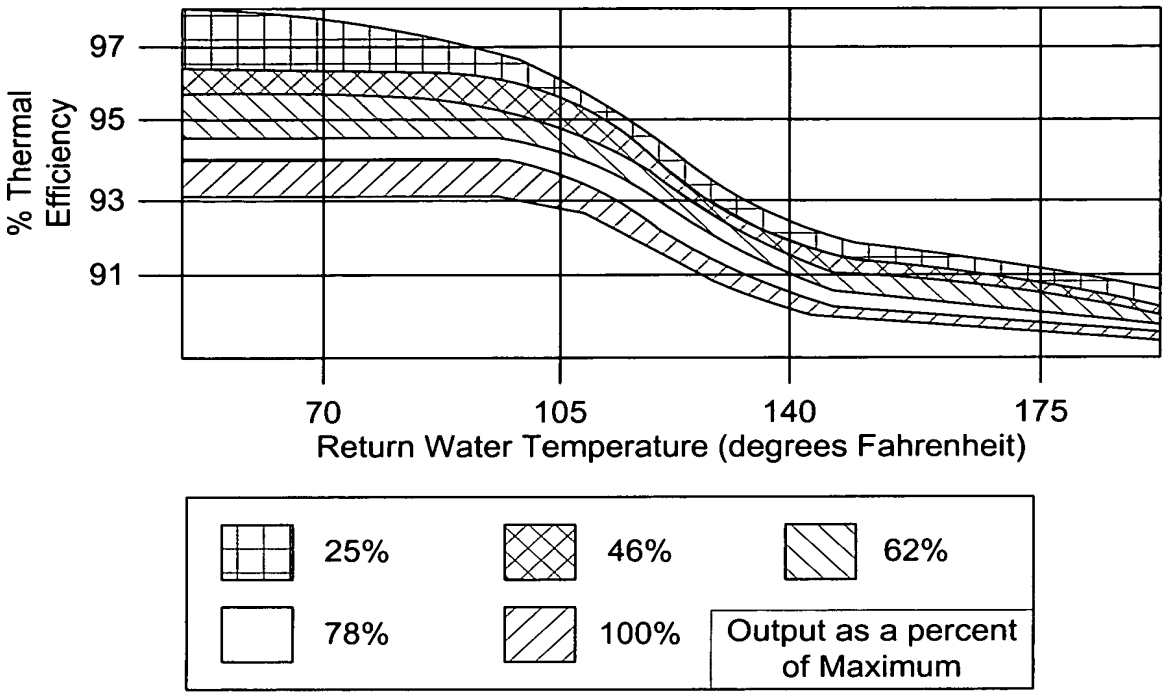

FIG. 1

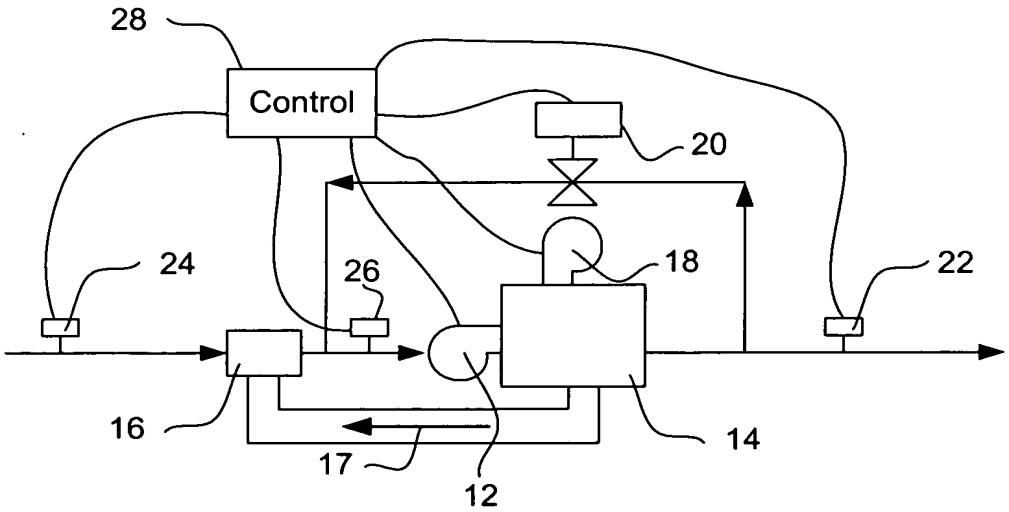

FIG. 2

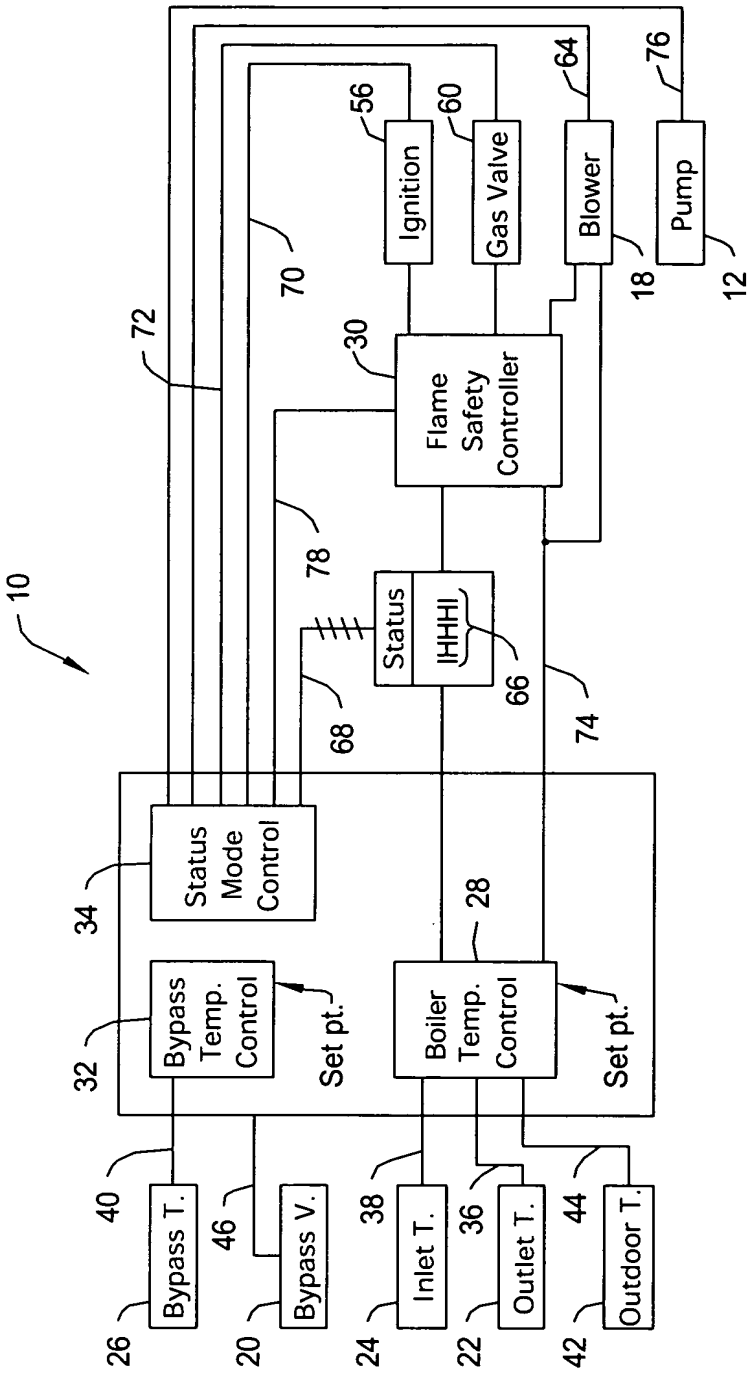
10
Ignition
56
Gas Valve
60
Blower
64
Pump
76
18
12
70
72
30
Flame Safety Controller
78
Status
IHHI
66
68
74
Status Mode Control
34
28
Bypass Temp. Control
32
Set pt.
Boiler Temp. Control
Set pt.
40
46
38
36
44
Bypass T.
Bypass V.
Inlet T.
Outlet T.
Outdoor T.
26
20
24
22
42

Fig. 3

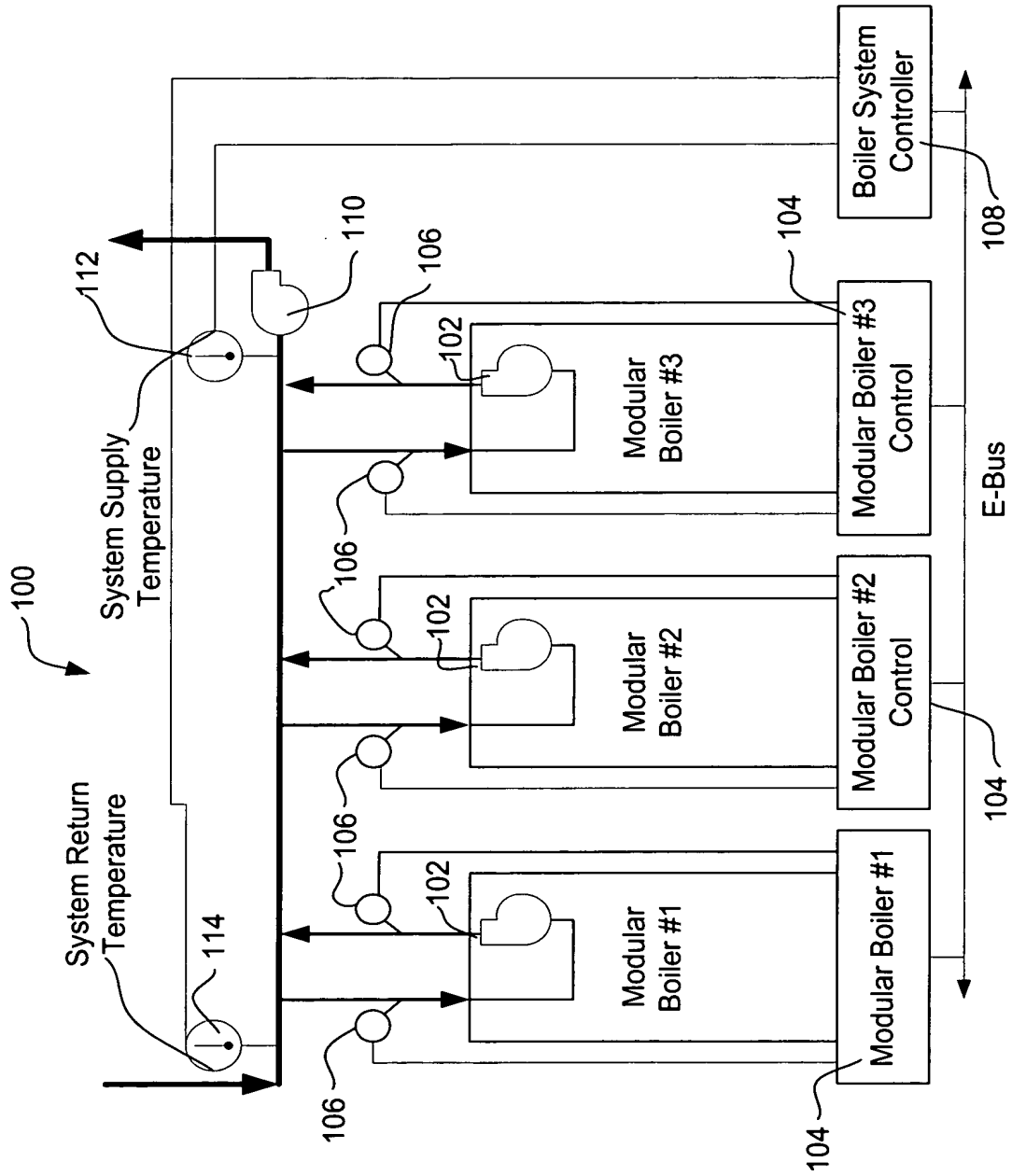
100
System Return Temperature
System Supply Temperature
112
114
110
106
102
104
108
Modular Boiler #1
Modular Boiler #2
Modular Boiler #3
Modular Boiler #1
Modular Boiler #2
Modular Boiler #3
Boiler System Controller
E-Bus

FIG. 4

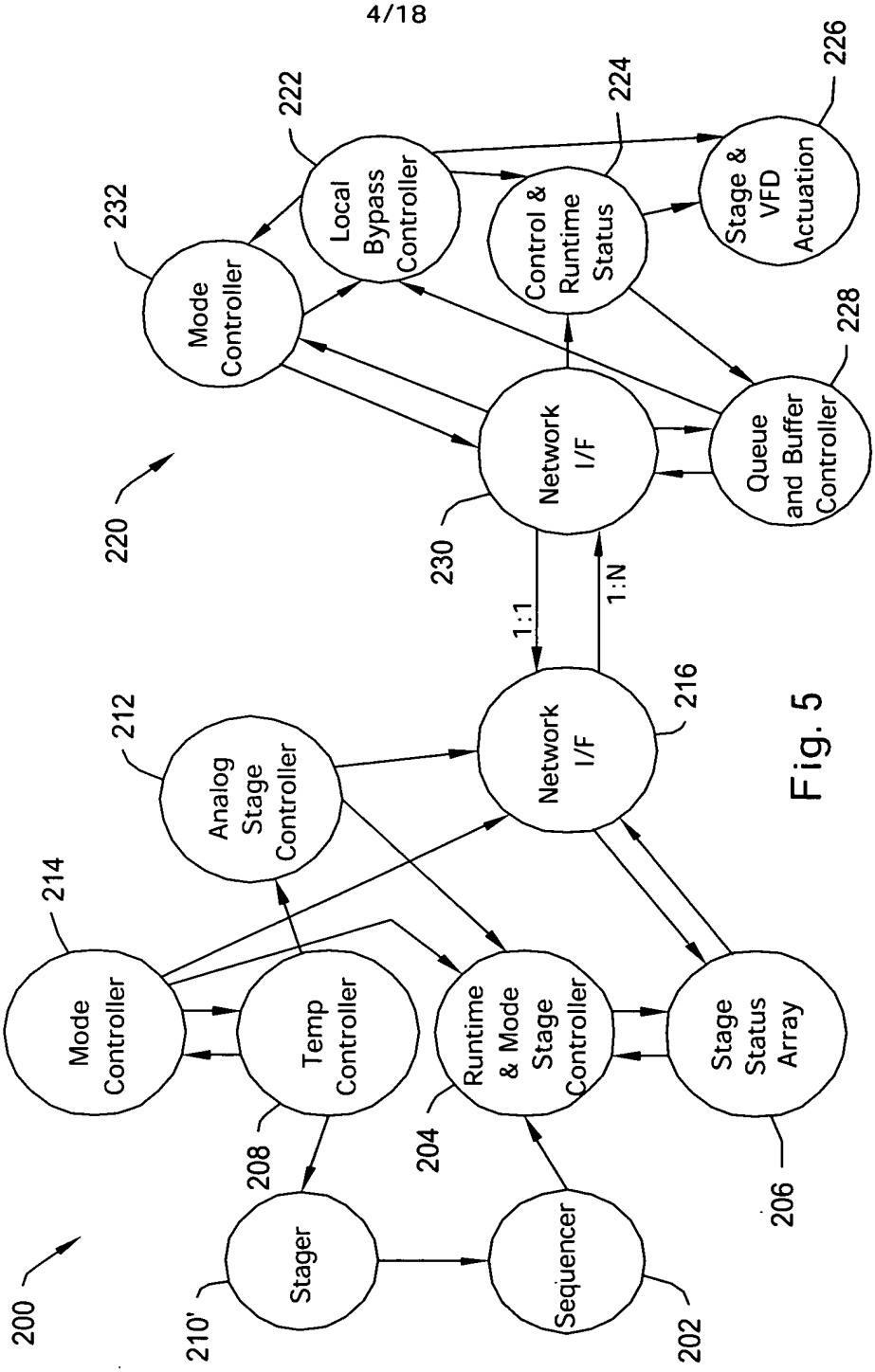
200
210'
Stager
208
Temp Controller
214
Mode Controller
204
Runtime & Mode Stage Controller
206
Stage Status Array
202
Sequencer
212
Analog Stage Controller
216
Network I/F
1:1
1:N
230
220
Network I/F
232
Mode Controller
222
Local Bypass Controller
224
Control & Runtime Status
226
Stage & VFD Actuation
228
Queue and Buffer Controller

Fig. 5

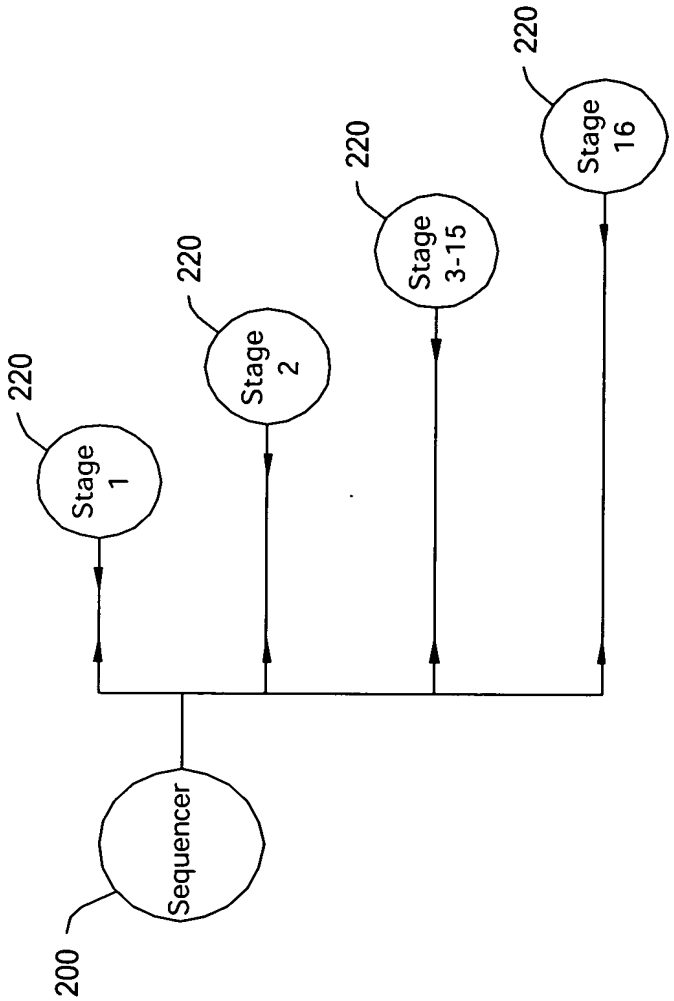
220
Stage 1
220
Stage 2
220
Stage 3-15
220
Stage 16
Sequencer
200

Fig. 6

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Sheet 6 of 18

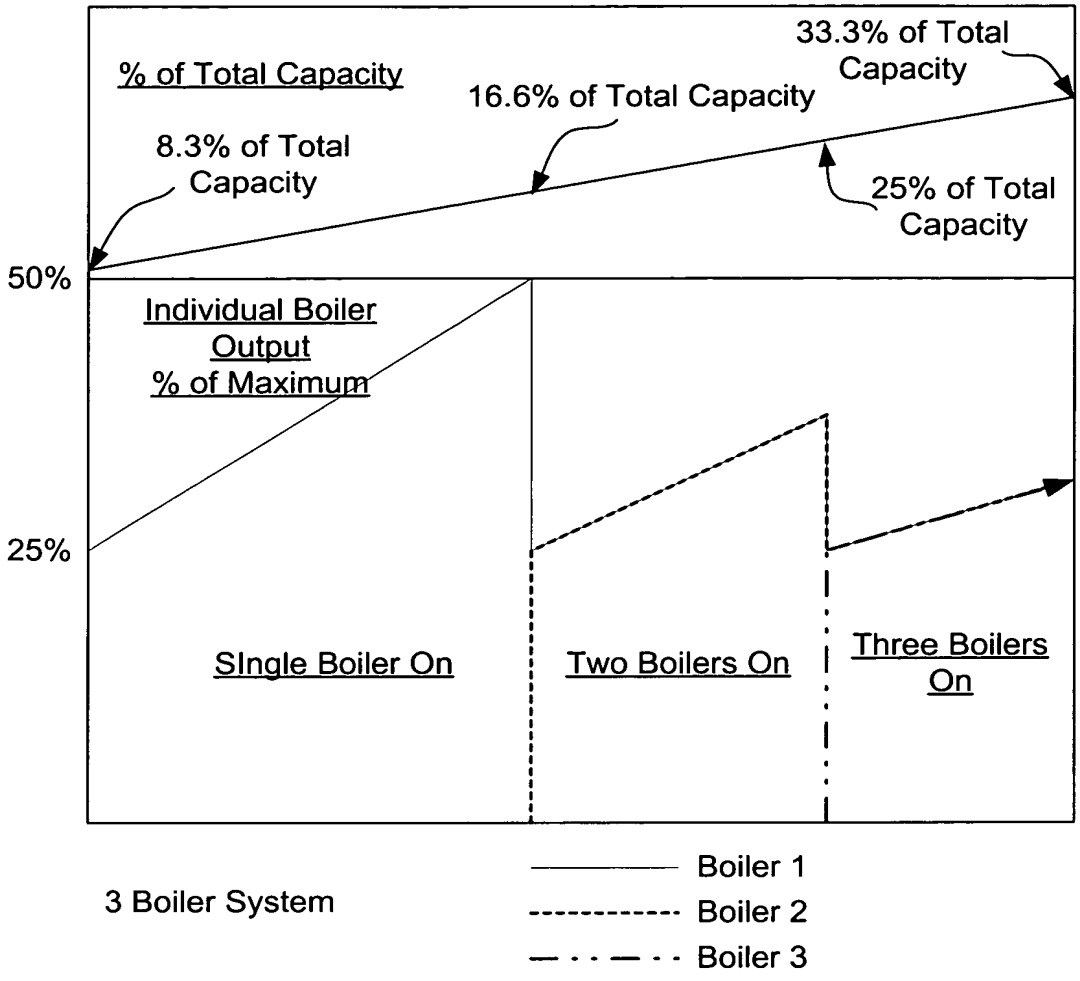


FIG. 7

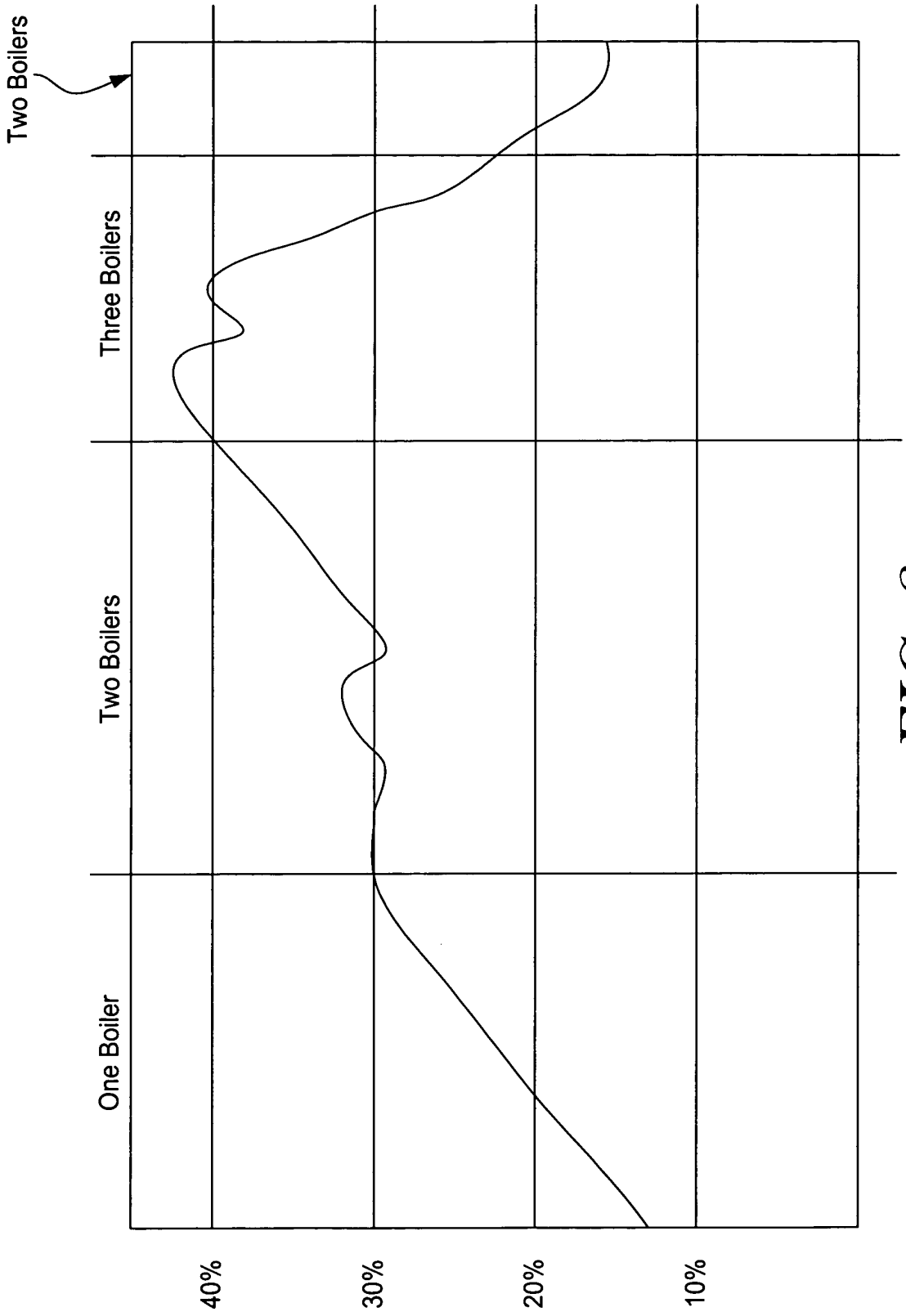


FIG. 8

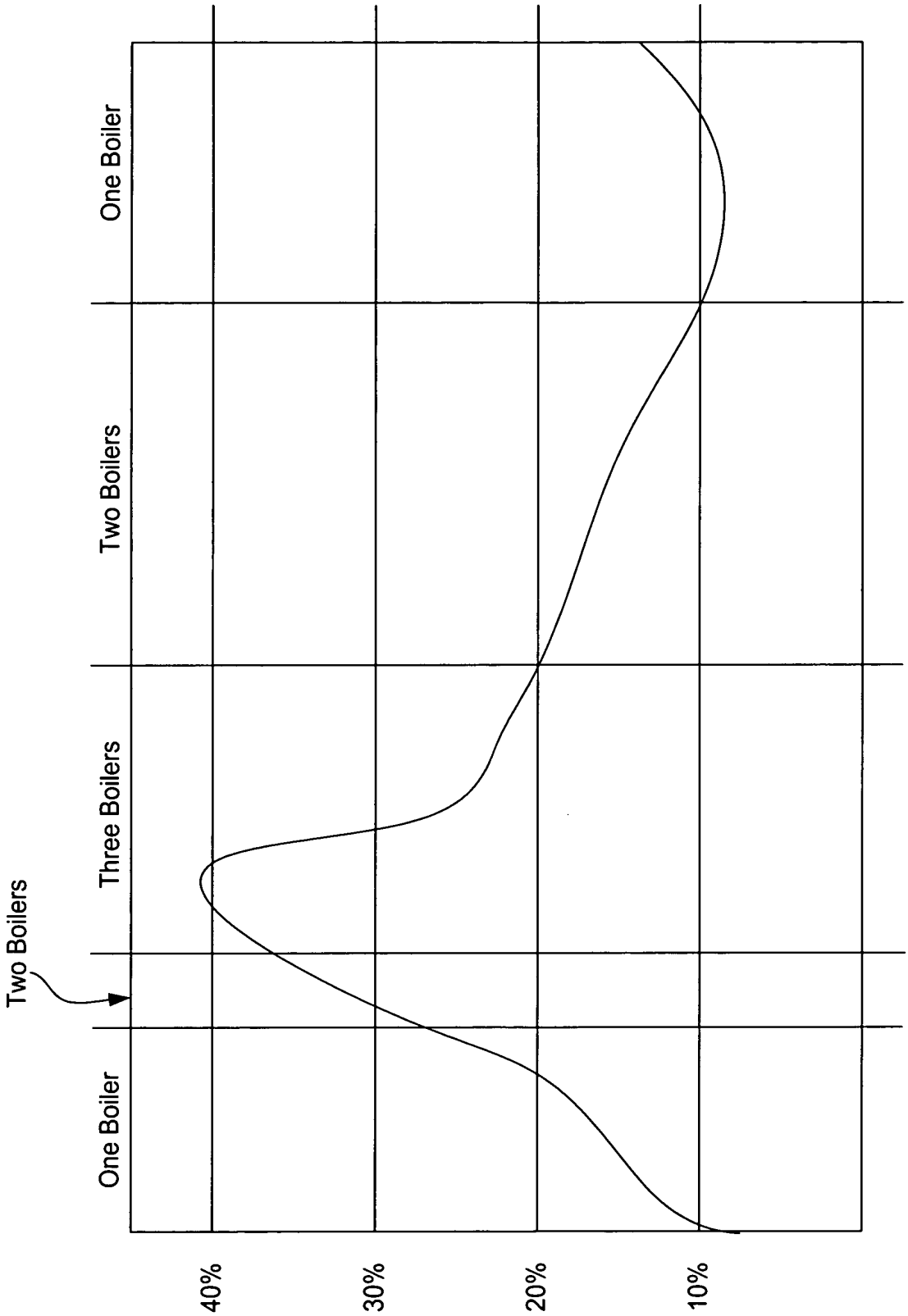

One Boiler
Two Boilers
Three Boilers
Two Boilers
One Boiler
40%
30%
20%
10%

FIG. 9

% Call	Derivative	Previous # of Boilers On	# of Boilers to Call Next
26	4	1	2
26	3	1	1
28	3	1	2
28	2	1	1
29	2	1	2
29	1	1	1
30	n.a.	1	2
34	-4	3	2
34	-3	3	3
32	-3	3	2
32	-2	3	3
31	-2	3	2
31	-1	3	3
30	n.a.	3	2
36	4	2	3
36	3	2	2
22	-3	2	1
22	-2	2	2
20	n.a.	2	1
40	n.a.	2	3
50	n.a.	n.a.	3
13	n.a.	n.a.	1

FIG. 10

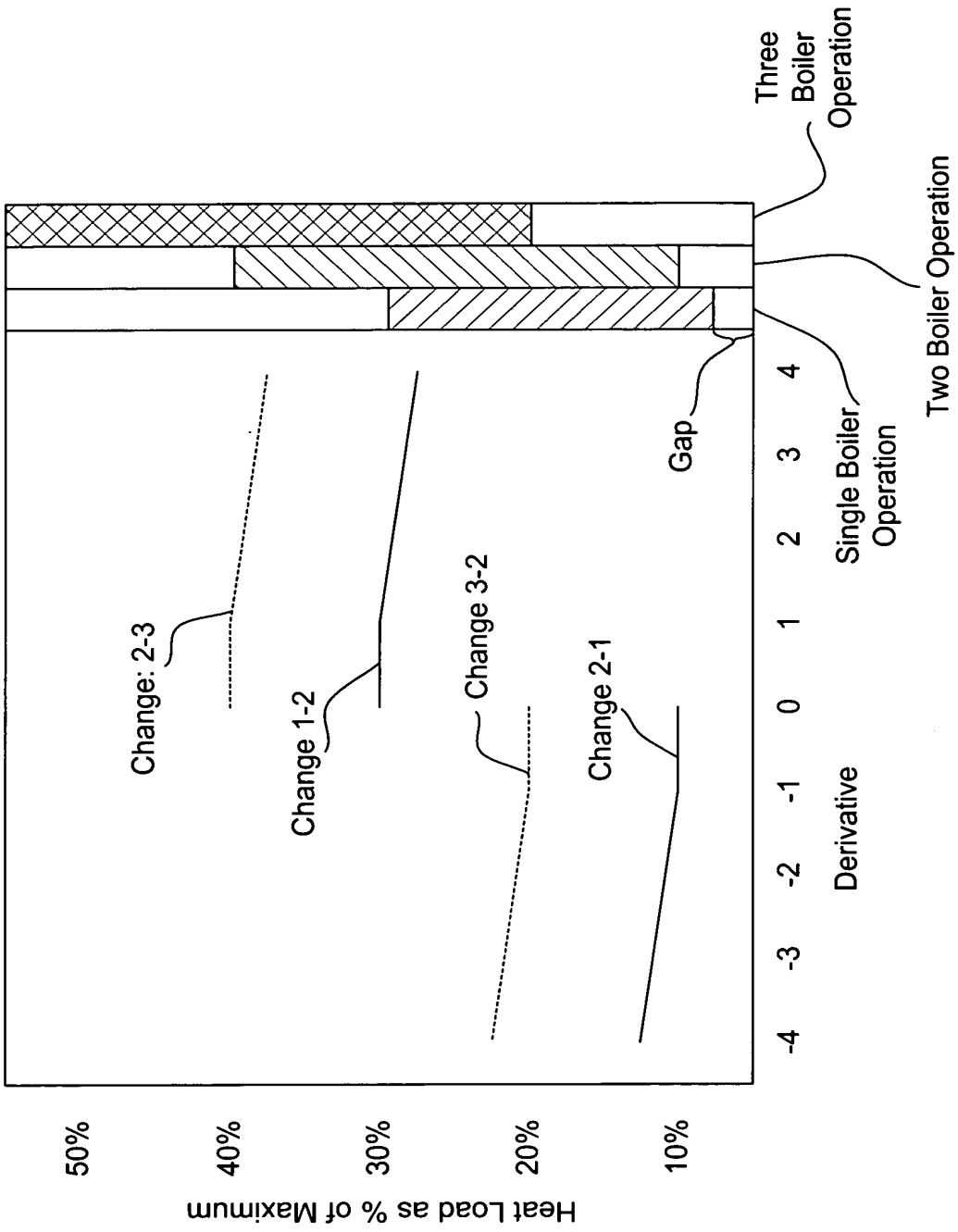
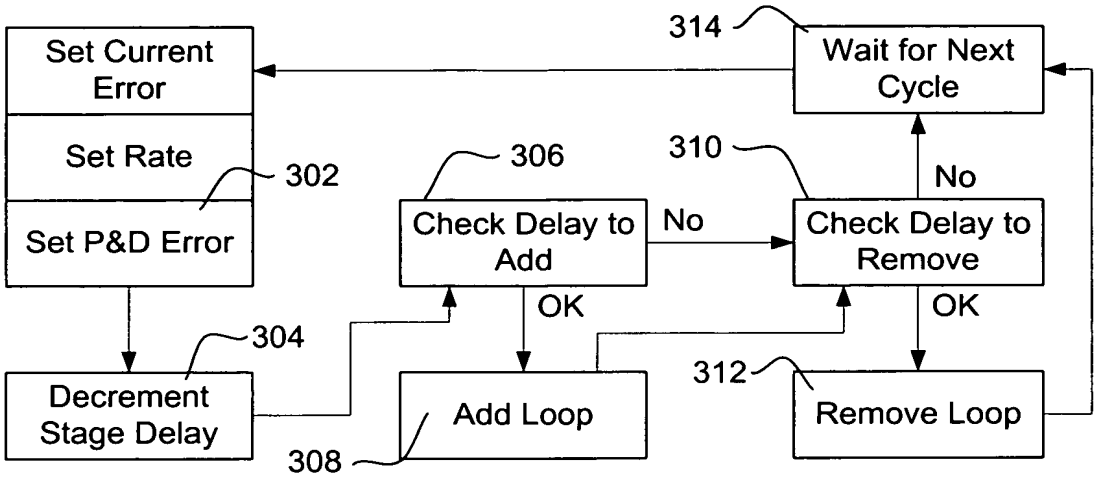

Heat Load as % of Maximum
50%
40%
30%
20%
10%
Derivative
-4
-3
-2
-1
0
1
2
3
4
Change: 2-3
Change 1-2
Change 3-2
Change 2-1
Gap
Single Boiler Operation
Two Boiler Operation
Three Boiler Operation

FIG. 11



300

Stager_Routine :// *Rate* = *every* 15 sec

current_error = *setpt* − *measured_value*;

rate = *measured_value* − *old_measured_value*;

old_measured_value = *measured_value*;

error = *current_error* − *k* * *rate*; // *user_adjustable_default* _(*k* = 3)

error = *upper* lim(*error*,+32);

error = *lower* lim(*error*,−32);

stage_delay = *stage_delay* − 1;

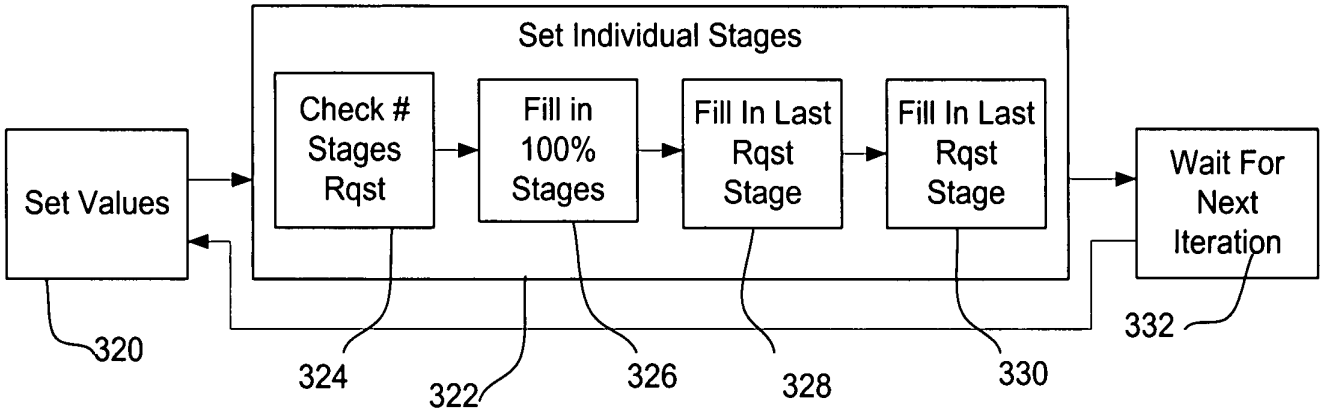
308

$$IF(stage_delay \le 0) : THEN : \begin{bmatrix} stage_delay = 0; \\ IF((error > throttling_range) AND (rate < 1/128)) : \\ THEN : \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst + 1; \\ stage_delay = 8; \end{bmatrix} \end{bmatrix}$$

312

$$IF(stage_delay \le 4) : THEN : \begin{bmatrix} IF((error < -throttling_range) AND (rate > -1/128)) : \\ THEN : \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst - 1; \\ stage_delay = 8; \end{bmatrix} \end{bmatrix}$$

FIG. 12



318

$Stage_Control : // period_of_5\text{sec}.$

$z = 0;$

$Heat_Command_Total = PID_Control(setpt, measured_value, throttling_range)$

$FOR(z < Num_Stages_Config):$

322

$$\left[IF : (Num_Stages_Rqst = 0) : \left[\begin{array}{l} FOR : (i = 0) to (i = Num_Stages_Config) : \\ Heat_Command[z] = 0. \end{array} \right]; \right.$$

$$IF : \left(Heat_Command_Total \geq \left(\frac{(z+1)*100}{Num_Stages_Config} \right) \right) : [Heat_Command[z] = 100]$$

$$ELSE : IF : \left(Heat_Command_Total < \left(\frac{(z)*100}{Num_Stages_Config} \right) \right) : [Heat_Command[z] = 0]$$

$$ELSE : [Heat_Command[z] = (Heat_Command_Total * Num_Stages_Config) - (z*100)]$$

$$z = z + 1; \left. \right]$$

FIG. 13

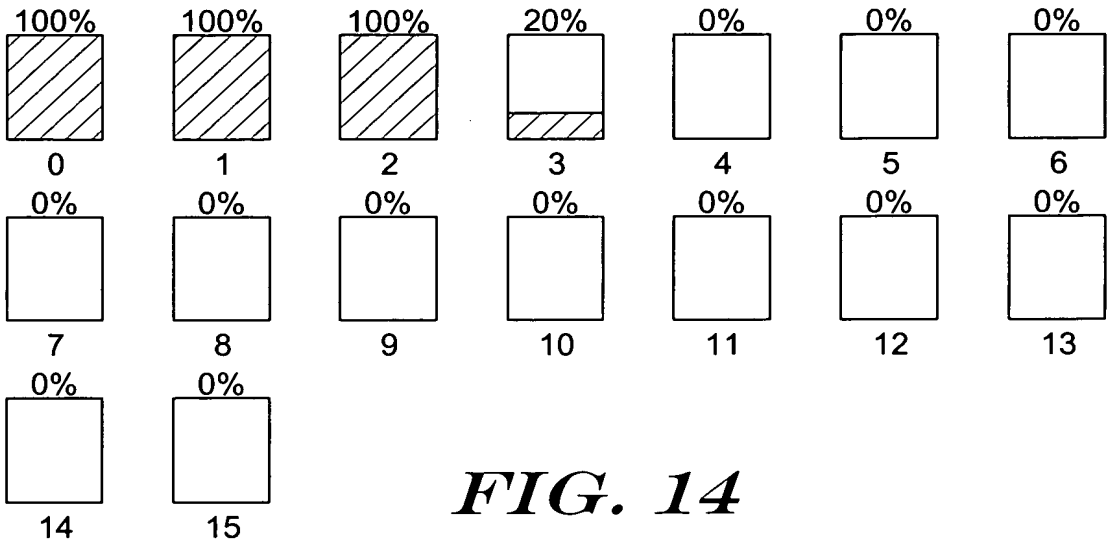

100%
0
100%
1
100%
2
20%
3
0%
4
0%
5
0%
6
0%
7
0%
8
0%
9
0%
10
0%
11
0%
12
0%
13
0%
14
0%
15

FIG. 14

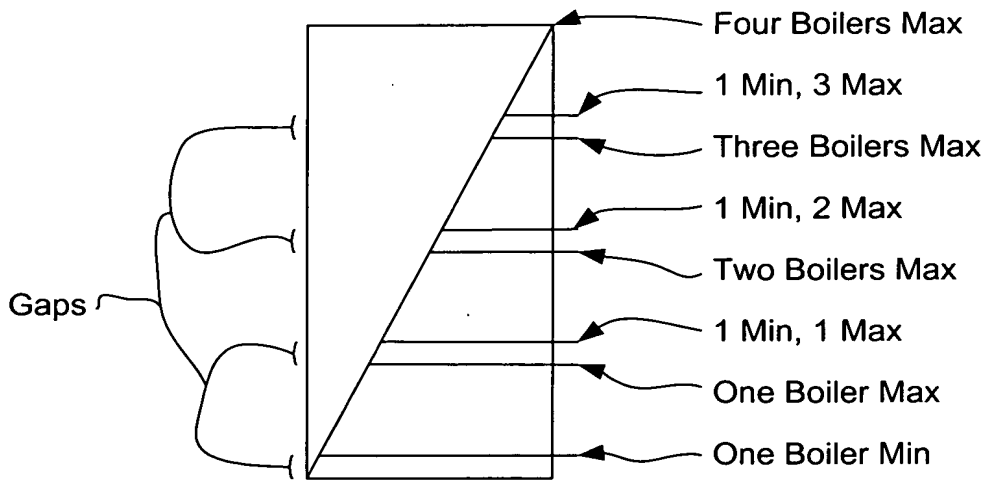

Four Boilers Max
1 Min, 3 Max
Three Boilers Max
1 Min, 2 Max
Two Boilers Max
1 Min, 1 Max
One Boiler Max
One Boiler Min
Gaps

FIG. 15

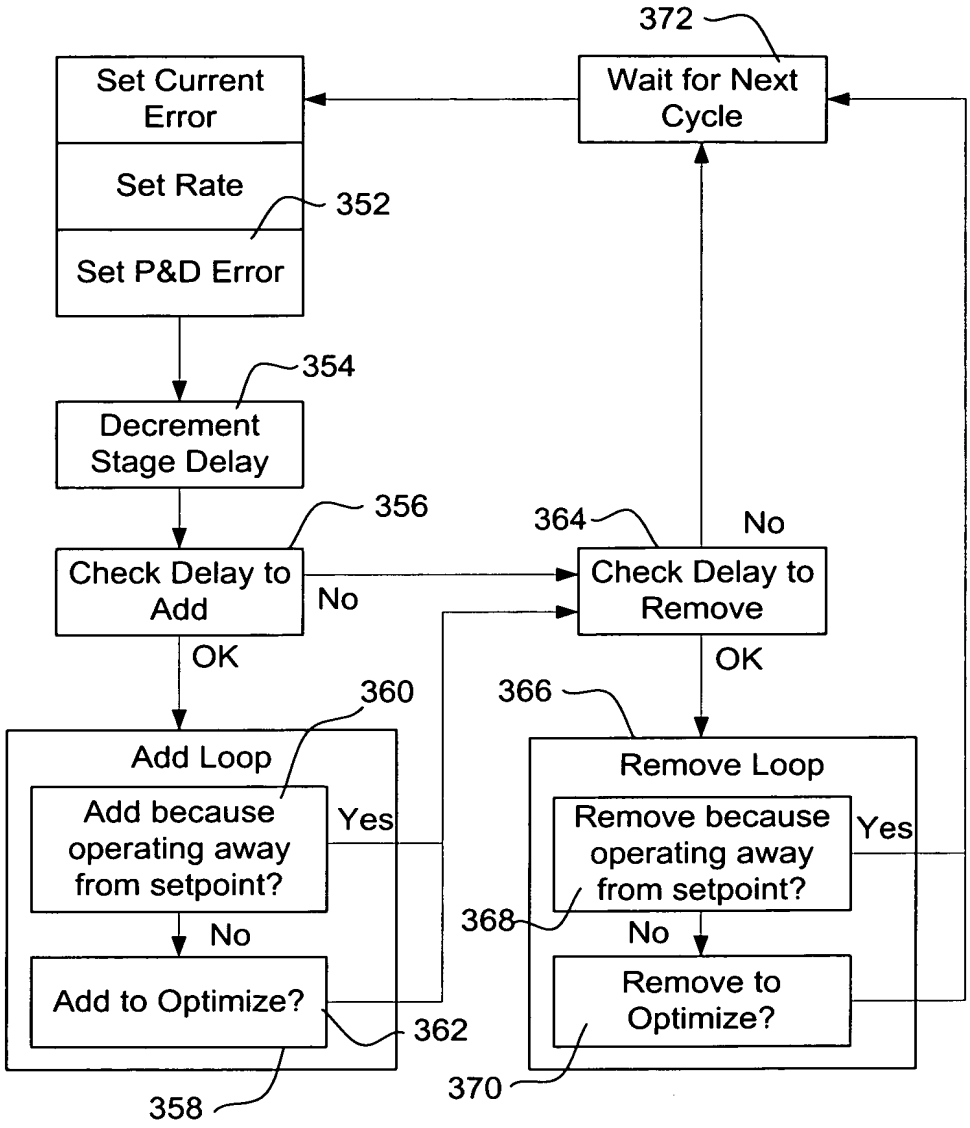

372
Wait for Next Cycle
Set Current Error
Set Rate
352
Set P&D Error
354
Decrement Stage Delay
356
Check Delay to Add
No
OK
360
Add Loop
Add because operating away from setpoint?
Yes
No
Add to Optimize?
362
358
364
No
Check Delay to Remove
OK
366
Remove Loop
Remove because operating away from setpoint?
Yes
368
No
Remove to Optimize?
370

FIG. 16A

Efficiency_Optimized_Stager_Routine:

Current_Error = Setpt − Measured_Value;

Rate = Measured_Value − Old_Measured_Value;

Old_Measured_Value = Measured_Value;

*error = (Current_Error − k * Rate)*; // *k = userchangeable_const.*

error = Upper_lim(error,+32);

error = Lower_lim(error,−32);

Stage_Delay = Stage_Delay − 1;

$$
\begin{bmatrix}
Stage_Delay = 0; \\
IF((error > Stager_Throttling_Range)AND(Rate < 1/128): \\
THEN: \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst + 1; \\ Stage_Delay = 8; \end{bmatrix} \\
ELSE, IF: \begin{bmatrix} (Current_Error < 1/128)AND(Rate < 0)AND \\ \left(Heat_Command_Total > \dfrac{100(Num_Stages_Rqst + 1)}{3 * Num_Stages_Conf} \right) \end{bmatrix}, \\
THEN: \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst + 1; \\ Stage_Delay = 8; \end{bmatrix}; \\
ELSE: [Do_Nothing];
\end{bmatrix}
$$

358

354

$IF(Stage_Delay \le 0):$

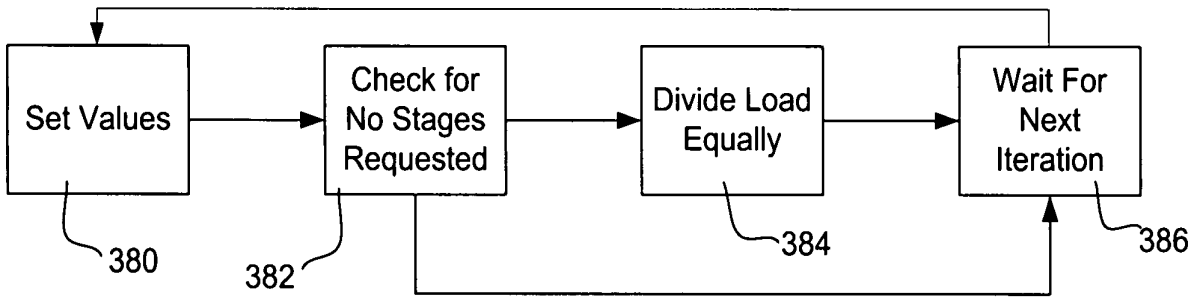
$$
\begin{bmatrix}
IF((error \le -Stager_Throttling_Range)AND(Rate > -1/128)) \\
THEN: \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst - 1; \\ Stage_Delay = 8; \end{bmatrix} \\
ELSE, IF: \begin{bmatrix} (Current_Error < 1/128)AND(Rate > \dfrac{-1}{16})AND \\ (Heat_Command_Total < \dfrac{90(Num_Stages_Rqst - 1)}{Num_Stages_Configured} \end{bmatrix} \\
THEN: \begin{bmatrix} Num_Stages_Rqst = Num_Stages_Rqst - 1; \\ Stage_Delay = 8; \end{bmatrix}
\end{bmatrix}
$$

366

364

$IF(Stage_Delay \le 4):$

FIG. 16B



Efficiency_Optimized_Stage_Control

$$Heat_Command_Total = PID_Control(setpt, measured_value, throttling_range)$$

$$IF(Num_Stages_Rqst = 0)$$

$$THEN: \left[\begin{array}{l} FOR(i = 0)to(i = Num_Stages_Config) \\ Heat_Command[i] = 0 \end{array} \right]$$

$$ELSE, FOR(i = 0)to(i = Num_Stages_Config):$$

$$\left[\begin{array}{l} Heat_Command[i] = \dfrac{Heat_Command_Total * Num_Stages_Configured}{Num_Stages_Rqst} \\ IF(Heat_Command[i] > 100; THEN: [Heat_Command[i] = 100]; \end{array} \right]$$

FIG. 17

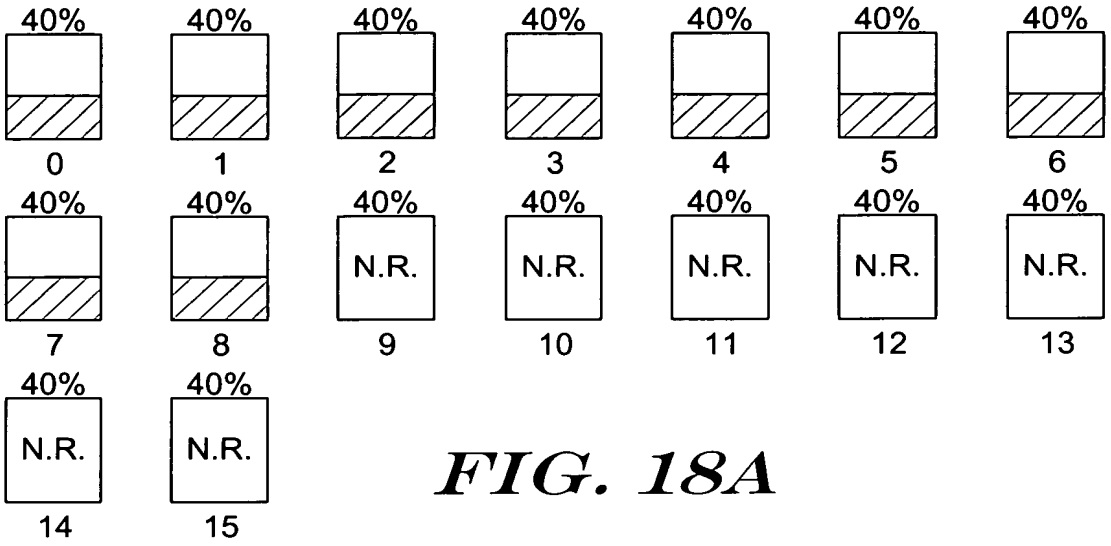


FIG. 18A

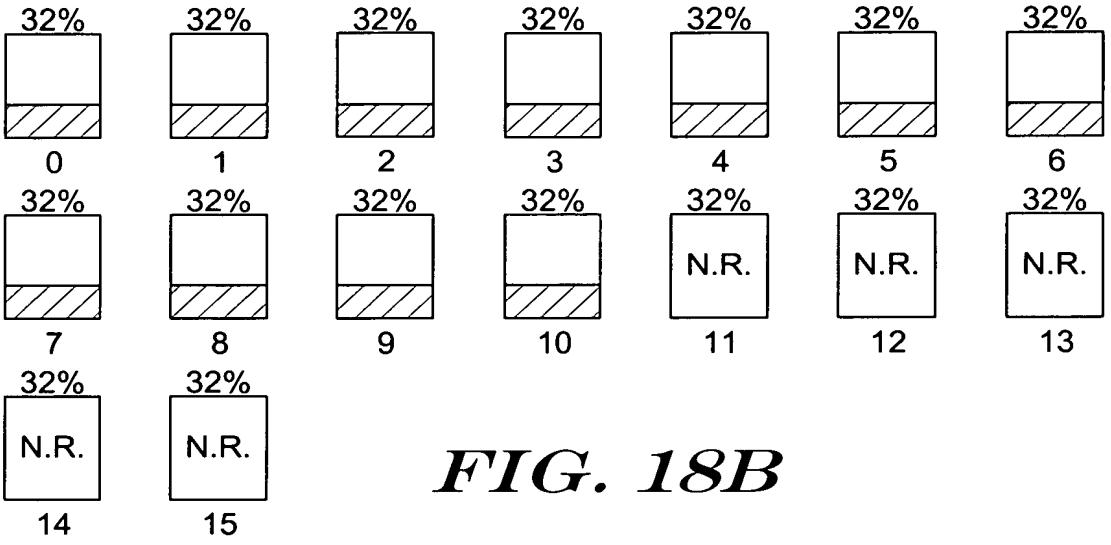


FIG. 18B

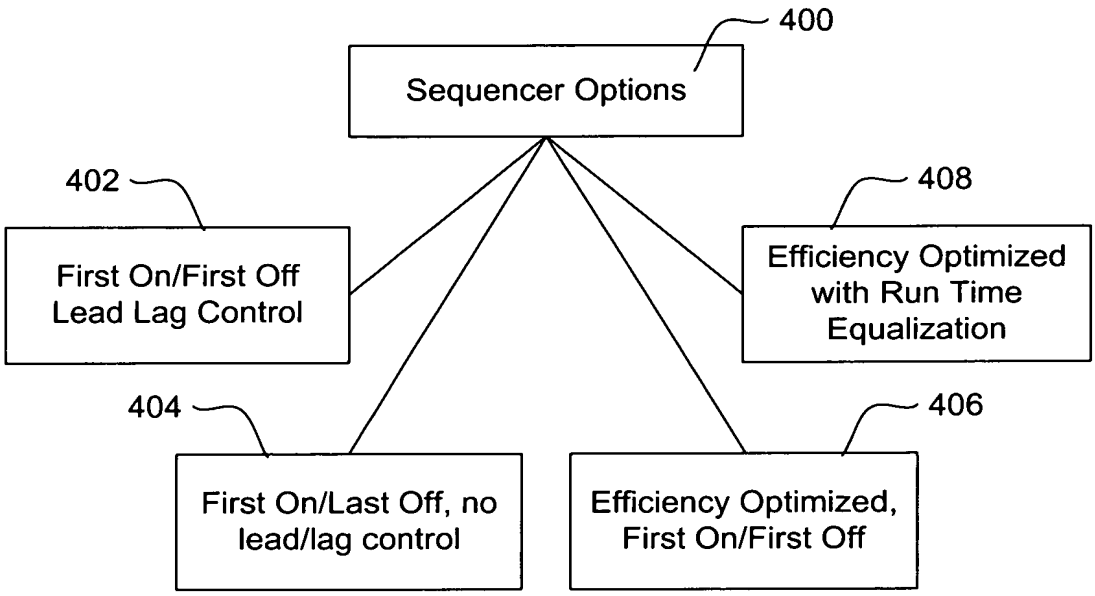

400
Sequencer Options
402
First On/First Off Lead Lag Control
408
Efficiency Optimized with Run Time Equalization
404
First On/Last Off, no lead/lag control
406
Efficiency Optimized, First On/First Off

FIG. 19